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THE EFFECTS OF A HIGH FAT DIET IN A TEMPERATE ENVIRONMENT[1]

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WITH THE TECHNICAL ASSISTANCE OF
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TWO FIGURES

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The belief that the eating of meat confers strength upon the eater is prominent in the folklore of many peoples. The evidence gathered by explorers and anthropologists during the last 100 years has proved conclusively that some very vigorous groups, for example the Eskimos, live exclusively upon meat. Furthermore some explorers themselves have lived entirely by hunting and one explorer, Stefanssen, has thrived upon a meat diet under controlled experimental conditions in a New York hospital (Stefanssen, '35–'36). There is no indication that such a diet decreases vigor. In those areas where food is obtained entirely from the animal carcass, the fatty tissues seem to be particularly prized. Indeed there is evidence to suggest that fat is essential and that a diet of lean meat alone causes marked illness in a very few days (Stefanssen, '35–'36). When both lean meat and fatty tissues are available in unlimited amounts, the natural tendency seems to be to eat enough fat so that most of the calories are derived from this

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source. Stefanssen ('44) believes that as much as 80% of the calories may come from fat.

In view of these observations which have extended over many years and many cultures, it is extraordinary to read of the results of recent experiments upon diets consisting exclusively of protein and fat (Kark, Johnson and Lewis, '45) in which it was clearly shown that the subjects upon these diets were not only incapable of hard work but even appeared to be no better off than if they had gone without food altogether. This sharp discrepancy between well established facts and recent experiments has puzzled us greatly. The most obvious difference between the two sets of observations is that the diets in the earlier work consisted of meat and fat eaten either raw or after ordinary cooking, while in the work of Kark, Johnson and Lewis ('45) pemmican was used. The pemmican was prepared by dehydrating cooked lean meat, grinding it up and then mixing it with melted fat. There is nothing in this process which would be expected to change the nutritional properties of the food (except the flavor) and yet there appeared to be a very great change in these properties. Could it be the dehydration? This seemed unlikely as there was no limitation of the water intake and no reason to suppose the protein was not rehydrated in the digestive tract. The subjects in Kark's experiments were only on the diet for 3 days. Was this too short a time to accustom them to the diet? To answer these and other questions we carried out a short preliminary study with twelve men on a field trip.

METHODS

A field trial was held for 3 weeks on a small island, Pasque, near Woods Hole, Buzzards Bay, Mass. The temperature ranged from 48°F. to 70°F., the weather being rainy and misty most of the time. The subjects, including three civilians and nine enlisted men, were laboratory workers, performing the qualitative and quantitative biochemical analyses essential to the study. The group was divided so that eight men acted as subjects and four men as controls. The controls ate a good packaged ration supplemented with bread, butter, jam, coffee, tea, and extra evaporated milk and sugar, and their daily intake of nutrients was, in all respects, at least as high as the standard recommended by the National Research Council. Their average protein intake was 105 gm per day, and fat accounted for 30% of their caloric intake. The experimental subjects ate pemmican, made by adding 50% of fat to 50% of ground dried leaf beef, with 1% salt added. On such a diet, 71% of the calories are derived from fat, 27% of the calories from protein, and 2% from carbohydrate. They had the choice of either tea or coffee without sugar or milk, and as much water as they wanted to drink. There was an initial period of 5 days on a normal diet, followed by 9 days' experimental period on pemmican and then a return to a normal diet for 4 days. Biochemical tests were made during all three periods.

On the first day of the diet, the subjects were each given a can of pemmican that weighed approximately 460 gm, containing 7 cal. per gm. They were cautioned to eat only 100 to 200 gm the first day or so and then only when really hungry. The reason for this warning was previous experience in which many subjects on changing from a normal diet to a high fat diet became nauseated and vomited during the first 2 days. A careful check was kept on the daily food consumption of each subject.

Biochemical and physiological measurements were made periodically. Body weight was measured daily. Fluid balance was calculated daily from body weight, fluid intake and fluid excretion. Physical fitness was measured by the "pack test" (Darling et al., '44; Johnson, Brouha and Darling, '42). Basal metabolic rate was measured by a Douglas bag method. Biochemical measurements and methods included: serum protein, Phillips et al. ('43); blood glucose, Folin and Malmros ('29); serum and urine chloride, Keys ('37); serum non-protein nitrogen, Daly ('33); serum cholesterol, Bloor ('26); serum and urinary ascorbic acid, Farmer and Abt ('36); urinary nitrogen, Ma and Zuazaga ('42); urinary riboflavin, thiamine and N^1-methylnicotinamide, Johnson, Sargent, Robinson and

Consolazio ('45); urinary ketone bodies, qualitative, Rothera (see Hawk and Bergeim, '37); bromsulfalein test of liver function, Rosenthal and White ('25); phenolsulfonphthalein test of kidney function; oral glucose tolerance test, Exton and Rose ('34); insulin tolerance test. Laboratory procedures were conducted by means of our portable field laboratory, Johnson ('45).

RESULTS

For the first day or so the subjects ate the pemmican warmed slightly, but this method was given up as the dehydrated meat had to be chewed for quite a long time, which made one nauseated. On the third day, one of the subjects found that after addition of water and boiling the mixture for ½ to 1 hour, it

TABLE 1

Daily intake of pemmican in grams.

SUBJECT	DAY OF DIET 1	2	3	4	5	6	7	8	9	TOTAL
M.C.	139	135	191	172	55	89	126	53	138	1098
F.C.	190	183	398	238	230	231	90	143	67	1770
W.F.	140	208	181	195	90	66	162	220	73	1335
P.K.	113	160	148	191	100	50	31	4	0	787
A.R.	81	61	49	39	0	0	0	0	0	230
G.S.	121	374	245	670	635	467	662	510	408	4093
J.S.	138	184	177	321	241	190	130	49	64	1494
R.W.	162	211	155	128	120	10	0	0	0	786
Ave.	136	190	193	244	184	138	150	122	94	1449

made a fair stew. This seemed to be the best way to eat the pemmican, for the amount consumed kept increasing daily up to the fourth day, to 244 gm per person (table 1). After the fourth day the amount decreased gradually, so that on the ninth and last day the average consumption was 94 gm (660 cal.). One subject, A. R., became nauseated on the first day and as a result ate only 230 gm during the whole experimental period. He felt that he would rather starve the last 5 days than run the risk of vomiting. Another subject, G.S., was quite the opposite. He ate about 200 gm per day for the first

3 days, and then ate from 400 to 674 gm daily (2800 to 4720 cal.) the remaining 6 days. For the last 3 days he ate from 50 to 150 gm more than the rest of the group put together. At the end, no subject had begun to enjoy the taste of the food nor to feel that he could live on it.

During the first few days morale was fair but deteriorated noticeably until the subjects became listless, disheartened and difficult to rouse to do any physical work. They preferred to avoid strenuous exercise, particularly if it was prolonged, but did quite well on the physical fitness test (lasting only 5 minutes), which everyone was compelled to do on every third day.

Physical fitness in the subjects, as measured by the "pack test," showed an increase in score from 65 to 74, during the first 2 days and then leveled off until the end of the diet. After 3 days on a normal diet, the score increased from 74 to 83. The controls, on the other hand, increased gradually from a score of 46 before the diet to 73, 3 days after the diet. The improvement during the first few days of the experiment is explained largely by the fact that most of the men were not in training at the beginning of the experiment. The constancy of the scores during the dietary period is misleading because the men were 5.9 kg lighter at the end of the period and no extra weights were added to the packs to compensate for their weight loss. Such a decrease in work done should be accompanied by a definite increase in score, whereas no increase in score was found. The controls improved continuouly during the dietary period, which suggested that the control diet was definitely better.

Body weight showed striking changes, the experimental subjects averaging 5.9 kg loss in weight as compared with the 1.0 kg lost by the controls (table 2). In 3 days of normal diet the experimental subjects regained 3.6 kg. Part of these changes were on a caloric basis because of the average daily caloric deficit of about 1500. Part was also due to change in water balance. In the subjects during the first 3 days on the diet more fluid was put out in the urine than was taken in by mouth; in the controls the intake always exceeded the urinary output

TABLE 2

Changes in body weight during and after pemmican.

SUBJECTS RECEIVING PEMMICAN	BEFORE 1	DAYS DURING 2	4	5	7	9	DAYS AFTER 1	3
M.C.	74.8	72.1	71.6	70.9	70.1	69.1	70.5	72.9
F.C.	95.0	92.1	90.6	90.5	89.5	87.7	90.3	90.8
W.F.	73.4	70.0	69.1	68.2	67.5	66.4	68.0	68.7
P.K.	75.0	72.7	72.2	71.3	70.0	69.0	71.9	72.9
A.R.	89.8	87.2	85.5	85.0	83.8	82.5	84.4	85.6
G.S.	65.9	62.8	64.2	63.1	63.7	62.9	64.5	66.3
J.S.	74.0	70.7	69.9	69.6	68.7	68.0	71.1	72.9
R.W.	66.7	65.4	64.2	64.2	61.9	60.4	62.5	65.0
Ave.	76.7	74.1	73.4	73.0	71.9	70.8	72.9	74.4
Controls								
J.E.	68.2	66.9		66.5		66.2	67.5	67.8
F.M.	79.7	79.6		79.7		79.2	79.4	79.2
J.P.	69.0	68.2		68.7		68.3	68.5	68.6
S.T.	64.3	65.0		64.6		64.1	64.2	64.8
Ave.	70.4	69.9		69.6		69.4	69.8	70.1

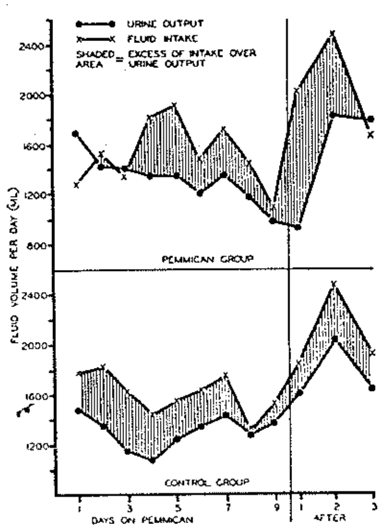

Figure 1

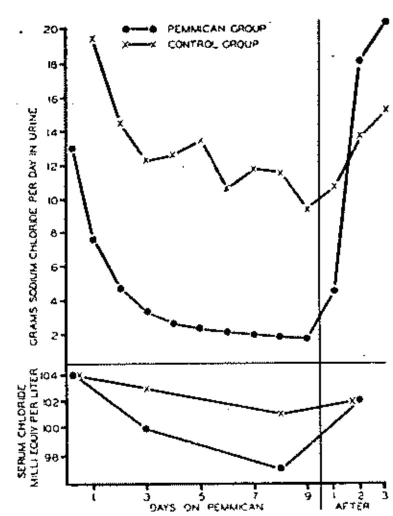

Figure 2

Fig. 1 Daily fluid intake and urine output.
Fig. 2 Serum and urine chlorides.

(fig. 1). At the same time the urinary excretion of chloride (fig. 2) and its serum level were dropping steadily in the subjects but not in the controls. For 2 days after resumption of normal diet, there was a large retention of water by the subjects with increasing serum chloride and urinary excretion of chloride.

TABLE 3

Measurements showing no significant difference between pemmican group and controls.

MEASUREMENTS AND UNITS	SUBJECTS	PERIOD OF TRIAL			
		Before 1 day	Experimental ration 4 days	9 days	After 3 days
Serum N.P.N.	Pemmican	35	40	32	28
mg/100 ml	Controls	35	28	30	27
Serum cholesterol	Pemmican	190		205	175
mg/100 ml	Controls	165		210	195
Serum ascorbic	Pemmican	0.6	0.4	0.5	0.4
acid mg/100 ml	Controls	0.3	0.2	0.4	0.4
Serum protein	Pemmican	6.7	6.8	6.7	6.3
gm/100 ml	Controls	6.5	6.6	6.2	6.5
Urine ascorbic	Pemmican	0.8	0.6	0.2	0.5
acid mg/hour	Controls	0.5	0.5	0.1	0.3
Urine thiamine	Pemmican	11	7	7	6
μg/hour	Controls	8	6	6	6
Urine riboflavin	Pemmican	76	41	32	53
μg/hour	Controls	63	46	31	42
Fasting blood	Pemmican	101	112	103	107
glucose mg/100 ml	Controls	100		107	112
Basal metabolic	Pemmican	+ 6	+ 9		0
rate % of normal	Controls	+ 5	+ 6		0
P.S.P. kidney	Pemmican	64	69		61
function % excreted in 2 hrs.	Controls	68	66		73

Of the many other measurements made, some, discussed later, showed differences between the experimental subjects and the controls, and the rest did not. The latter are listed in table 3 and included: serum NPN, serum cholesterol, serum ascorbic acid, serum protein, fasting blood sugar, BMR, kidney function tests, urinary ascorbic acid, thiamine and riboflavin. Significant differences were found in urinary ketone bodies, nitrogen, N^1-methylnicotinamide and the tests of glucose tolerance, insulin tolerance and liver function. These will be discussed below.

Beginning on the first day of the diet, the subjects had a ketosis, a two-plus positive nitroprusside reaction in the urine which increased to a four-plus from the fifth to the ninth days, and it was not until the third day after the diet that they showed a negative nitroprusside reaction again. This ketosis was shown equally by the subjects who ate the most and the least (G.S and A.R.).

The excretion of N^1-methylnicotinamide increased in the experimental subjects from 0.44 mg per hour to 0.96 mg per hour but the controls stayed practically constant at 0.32 before to 0.42 mg per hour during the experimental period. It was not an effect of starvation as shown by subject G.S. who kept in caloric balance, but was probably due to the large intake of protein.

The urinary excretion of nitrogen averaged 173 gm (1080 gm protein) per person for the 9-day period, the highest daily output being 24.4 gm and the lowest 14.2 gm, which was still high. On the other hand the average nitrogen intake was 103 gm per person (644 gm protein) which was a deficit of 70 gm nitrogen during the whole experimental period. Thus even though the subjects took in reasonable amounts of protein (average 50 gm/day omitting subject G.S. or 69 gm/day including G.S.), all except G.S. still burned their body protein at the average rate of 49 gm per day to help supply their caloric deficiency. The only subject (G.S.) who did not have a caloric deficiency ate 265 gm of protein per day and did not use any of his body nitrogen; in fact he had a positive nitrogen balance.

There were significant changes in both the insulin and glucose tolerance tests (tables 4 and 5). During the period of the diet the blood glucose of the pemmican group did not fall to abnormally low levels either in the basal state or after 2.5

units of crystalline zinc insulin were injected intravenously, but the depression after insulin was definitely prolonged. The most interesting part of the insulin tolerance tests was the reactions that the subjects showed during the dietary period. Whereas no one had any marked symptoms before or after the diet, five of the eight men who had insulin tolerance tests

TABLE 4

Insulin tolerance tests.

GROUP	BLOOD GLUCOSE (MG/100 ML)						
	Fasting	20 min.	25 min.	30 min.	35 min.	45 min.	60 min.
Pemmican							
Before diet	111	83	80	83	93	106	105
Test period	107	77	74	70	80	85	85
After diet	119	83	79	85	87	106	107
Control							
Before diet	106	76	80	88	92	93	96
Test period	108	73	75	83	90	102	106
After diet	112	66	72	86	96	105	106

TABLE 5

Glucose tolerance tests. (All subjects received 75 gm of glucose).

TIME OF TEST	BLOOD GLUCOSE (MG/100 ML)					BLOOD GLUCOSE (MG/100 ML)				
	Fasting	30 min.	60 min.	120 min.	180 min.	Fasting	30 min.	60 min.	120 min.	180 min.
	Pemmican					*Control*				
Before diet	99	168	168	117	102	100	159	145	136	100
Test period	108	173	186	128	104	110	146	135	117	100
After diet	106	159	135	110	113	121	180	148	124	103

during the diet complained of faintness, light headedness, dizziness, hunger pains and nausea. The subjects became pale, sweated considerably and were noticeably glassy-eyed. Each subject received 2.5 units of crystalline zinc insulin intravenously, except W.F. and P.K. who both received 1.6 units. Even with such small doses W.F. had quite a bad reaction, which included nausea, faintness and hunger pains.

The results of the glucose tolerance tests were a surprise to all, for we had expected to see the subjects, on being given the glucose solution during the period on this diet, perk up and become happy and active. Instead, no subject detected any beneficial effects. The blood sugar curves during the glucose tolerance tests were significantly higher in the pemmican group.

TABLE 6

Liver tolerance test.[1]

TIME OF TEST	DYE RETAINED (%)			DYE RETAINED (%)		
	15 min.	30 min.	45 min.	15 min.	30 min.	45 min.
	Pemmican			*Control*		
Before diet	29	12	5	21	9	7
Test period	50	20	12	30	10	5
After diet	29	9	6	24	6	5

[1] 5 mg Bromsulfalein intravenously per kg of body weight.

The ketonuria, which did not disappear until 3 days after the diet was caused not only by starvation but also by the high fat and very low carbohydrate diet. This was shown very clearly during a glucose tolerance test in two different subjects. The nitroprusside reaction was a four-plus before drinking 75 gm of glucose in solution but in 1 hour in one case and 2 hours in another the reaction was negative. We will discuss the ketonuria again later in the paper.

The liver function test during the test period showed a significant increase in the retention of the dye at 15, 30 and 45 minutes (table 6).

DISCUSSION

For practical purposes, the present work supports the contention that pemmican is unsuitable for a field ration if used as the sole component.

At the beginning of the experiment, all the subjects seemed sure that they would have no trouble eating the pemmican, for at first it did not taste too badly when eaten slightly warmed and in small amounts, but this method was soon given up because it began to be very nauseating. The idea of eating it in the form of a stew also seemed to be good, but here again the novelty wore off within 2 days because the taste of the meat became more and more repulsive as days went by and as a result the amount consumed per person decreased gradually so that on the last day the average consumption was 94 gm (660 cal.).

Kark, Johnson and Lewis ('45) made a thorough search of the literature of explorers in cold climates and reported that there was no clear evidence that men had ever lived successfully on pemmican alone. It was always supplemented with biscuits and cereals and whatever other foods were available. The pemmican was commonly saved until the end, either because it was not liked or possibly because it was the most concentrated and expensive food. Stefanssen ('44), on the other hand, states that a fair test of pemmican should take at least 2 weeks, and in that time a person will grow to like it, but we found that the pemmican was edible in only very small amounts, not sufficient to keep a man in good condition for a long time. We had hoped to acquire a taste for it as days went by but instead it became more and more difficult to eat as time went on. The one subject who ate the most had to force himself through the last half of the experimental period. However, Peary ('17) and Priestley ('15) were enthusiastic about pemmican as the major component of a ration.

Each night the subjects in response to questions concerning subjective feelings and cravings agreed that they would much rather have almost anything to eat in place of pemmican. Many mentioned carbohydrate food but meats were also mentioned occasionally and there was no clear craving for carbohydrate. All had had visions of eating enormous quantities of food on the first meal after the diet, but when this hoped for meal at last came, almost everyone complained that he was filled and satisfied too soon. The average caloric consumption of the subjects at this meal was 1380 cal. and one of the most striking features was that all men ate large amounts of bacon and butter although carbohydrate food was equally available.

This suggests that people in general will eat fat that is naturally in food, but will not eat it in the form of pemmican.

The subjects, after having lost so much weight during the diet, retained an average of 1300 ml of fluids on the first day on a normal diet. We feel that the high fat had a tendency to slightly dehydrate the men, as shown in the case of G.S., who ate large quantities of the pemmican. However, our data are not adequate to differentiate between the effects of high fat and the effects of low chloride upon the water balance. G.S. still lost 3.0 kg in the 9-day period, but all of it was water because the calculated weight change from daily caloric intake and daily expenditure was plus 0.2 kg. This would make his water loss 3.2 kg. G.S. in contrast to the other subjects had slightly more than regained his normal weight by the third day on a normal diet. The weight loss of the whole group, calculated from their estimated caloric deficiency, was 1.7 kg which subtracted from the observed loss of 5.9 kg leaves 4.2 kg due to loss of fluid. The weight regained by the whole group by the third day on a normal diet was only 3.6 kg.

The general physiological findings of the present study confirm and extend the conclusions of Kark, Johnson and Lewis ('45). The biochemical abnormalities produced in our subjects by the high fat diet even in the one who ate the most, included changes in water and salt balance, liver function and glucose and insulin tolerance tests. While the subjects showed a marked ketosis, as might well be expected on this type of diet, it is not clear that this ketosis was detrimental. Heinbecker ('28) has shown that Eskimos on a meat diet do not show ketosis. Our subjects showed no change in scores in the physical fitness tests except for the initial 2 days but their daily work output was small and caloric deficits affect physical fitness most strikingly in men who are working hard.

There was unusually high sensitivity to insulin in five of the eight subjects on pemmican. In the literature very little is said about sensitivity to insulin on a high fat diet, but Himsworth ('34a) states that on a high fat diet the sensitivity to insulin is low and that subsistence on such a diet retards and diminishes the action of insulin upon the blood sugar. Wishnofsky, Kane and Spitz ('37) conclude that fat does not require insulin for its metabolism for it does not inhibit or retard the action of insulin. Riesser ('42) also states that a protein and fat diet produces a greater decrease in sensitivity to insulin shock than a diet consisting partly or largely of carbohydrate. Some work has been done on the sensitivity to insulin in starvation. Selye ('40) in experiments with rats, states that although fasting progressively increases the insulin sensitivity, there is a transitory period after about 2 days of starvation during which the insulin sensitivity is very low. Gigante ('35) in experiments with starving pigeons, states that the insulin resistance shows a sudden decrease at the point of hunger crisis, usually ending in convulsions. We cannot agree with Himsworth, Wishnofsky, and Riesser, for one of our subjects, G.S., who ate large quantities of the high fat diet, had a bad reaction during the insulin tolerance tests. Another subject, R.W., who practically starved the last 4 days, had reactions that were so severe that glucose had to be administered. To conclude, a high fat diet as well as a semi-starved condition, increased sensitivity to insulin as judged by the reactions other than the fall in blood sugar which fall was not increased though it was prolonged.

The glucose tolerance curves during the dietary regime which were significantly higher are in agreement with those of Himsworth ('34b), Threadwell, King, Babb and Tidwell ('42), and Greene and Swanson ('40), who all state that a high fat diet produces a decrease in sugar tolerance. Wilson ('39) states that the glucose tolerance curve has been employed successfully to detect early deficiencies in liver function. The curve in such cases is high and its fall is delayed and liver extract lowers it towards the normal.

There was increased retention of bromsulfalein dye during the experimental diet. Abnormal retention of the dye has been interpreted as evidence of liver dysfunction (Rosenthal and White, '25; Bulmer, '28; Foley, '30; Macdonald, '38; Helm and Machella, '42). There is general agreement that a retention of over 5% at 30 minutes is abnormal. One case of Robertson, Swalm and Konzelmann ('32) showed 100% retention and the interpretation was made that an important factor may have been dehydration and decrease in blood volume. In the present experiments there is evidence of changed liver function, not necessarily dysfunction. A hypothesis to explain the findings is that on a high fat diet, the mechanisms for regulating glycogen in the liver are altered in such a way that a given dose of insulin keeps the blood sugar at a low level for an abnormally long time. The bromsulfalein test confirms the alteration of liver function.

The urinary and serum chlorides, which were significantly low at the end of the diet, showed that even though a man ate more than his share of the pemmican daily, as in the case of G.S. who ate from 2800 to 4720 cal., the salt content was insufficient to keep the average man in salt balance with a satisfactory margin of safety over a long period of time. At the end of the diet G.S. was excreting only 5.7 gm of salt per day and his serum chloride had dropped from 106 to 100 milliequivalents per liter.

SUMMARY

A group of eight men living in a cool environment and doing work consisting mostly of laboratory procedures subsisted for 9 days on a high fat diet (pemmican) providing 71% of the calories from beef fat and 2% from carbohydrate. Four controls subsisted on a diet adequate in all respects and providing 30% of the calories from fat.

The utility of pemmican alone as a field ration for ordinary men was very poor because of the inability of all but one subject to eat enough of it. Morale deteriorated on the diet and most of the men resigned themselves to semi-starvation for the duration of the diet, mainly because of the nauseating taste. Nevertheless, scores in a physical fitness test remained practically constant.

Significant biochemical and physiological changes occurred, even in the one man who ate adequate amounts of the pemmican. These included: (a) an average weight loss of 5.9 kg,

much of it water; (b) change in water balance, with loss of body water; (c) salt depletion as measured by serum and urinary chlorides; (d) marked ketonuria; (e) alteration in the glucose tolerance curve, with prolongation of the rise but without alteration of the maximum; (f) alteration in tolerance to a given dose of insulin with much increased physiological reaction and prolongation of the decrease without alteration in the minimum; (g) increased retention of bromsulfalein. All of the above abnormalities were repaired in 3 days of normal diet.

Measurements showing no significant changes include: (a) serum protein; (b) serum non-protein nitrogen; (c) serum ascorbic acid, (d) serum cholesterol; (e) fasting blood glucose; (f) urinary excretion of thiamine, riboflavin and ascorbic acid; (g) basal metabolic rate; (h) phenolsulfonphthalein test of kidney function.

This work should not be taken to apply to all high fat diets, but at this point we do not know why there appears to be a difference between a diet of pemmican and a diet of fresh meat and fat.

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